

**IN THE UNITED STATES PATENT AND TRADEMARK OFFICE**

07/27/00  
JC803 U.S. PTO

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Title: SPEECH SIGNAL DECODING  
METHOD AND APPARATUS  
Appl. No.: Unassigned  
Filing Date: 07/27/2000  
Examiner: Unassigned  
Art Unit: Unassigned

JC836 U.S. PTO  
09/627421  
07/27/00

**UTILITY PATENT APPLICATION**  
**TRANSMITTAL**

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Box PATENT APPLICATION  
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Enclosed are:

- [ X ] Specification, Claim(s), and Abstract (43 pages).
- [ X ] Formal drawings (5 sheets, Figures 1-5).
- [ X ] Declaration and Power of Attorney (2 pages).
- [ X ] Assignment of the invention to NEC CORPORATION.
- [ X ] Assignment Recordation Cover Sheet.
- [ X ] Information Disclosure Statement.
- [ X ] Form PTO-1449 with copies of 4 listed reference(s).

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## Specification

## Title of the Invention

## Speech Signal Decoding Method and Apparatus

5 Background of the Invention

The present invention relates to encoding and decoding apparatuses for transmitting a speech signal at a low bit rate and, more particularly, to a speech signal decoding method and apparatus for improving the  
10 quality of unvoiced speech.

As a popular method of encoding a speech signal at low and middle bit rates with high efficiency, a speech signal is divided into a signal for a linear predictive filter and its driving sound source signal  
15 (sound source signal). One of the typical methods is CELP (Code Excited Linear Prediction). CELP obtains a synthesized speech signal (reconstructed signal) by driving a linear prediction filter having a linear prediction coefficient representing the frequency  
20 characteristics of input speech by an excitation signal given by the sum of a pitch signal representing the pitch period of speech and a sound source signal made up of a random number and a pulse. CELP is described in M. Schroeder et al., "Code-excited linear prediction:  
25 High-quality speech at very low bit rates", Proc. of IEEE Int. Conf. on Acoust., Speech and Signal Processing, pp. 937 - 940, 1985 (reference 1).

Mobile communications such as portable phones require high speech communication quality in noise environments represented by a crowded street of a city and a driving automobile. Speech coding based on the above-mentioned CELP suffers deterioration in the quality of speech (background noise speech) on which noise is superposed. To improve the encoding quality of background noise speech, the gain of a sound source signal is smoothed in the decoder.

10           A method of smoothing the gain of a sound source signal is described in "Digital Cellular Telecommunication System; Adaptive Multi-Rate Speech Transcoding", ETSI Technical Report, GSM 06.90 version 2.0.0, January 1999 (reference 2).

15           Fig. 4 shows an example of a conventional speech signal decoding apparatus for improving the coding quality of background noise speech by smoothing the gain of a sound source signal. A bit stream is input at a period (frame) of  $T_{fr}$  msec (e.g., 20 msec),  
20           and a reconstructed vector is calculated at a period (subframe) of  $T_{fr}/N_{sfr}$  msec (e.g., 5 msec) for an integer  $N_{sfr}$  (e.g., 4). The frame length is given by  $L_{fr}$  samples (e.g., 320 samples), and the subframe length is given by  $L_{sfr}$  samples (e.g., 80 samples). These numbers of  
25           samples are determined by the sampling frequency (e.g., 16 kHz) of an input signal. Each block will be described.

The code of a bit stream is input from an  
 input terminal 10. A code input circuit 1010 segments  
 the code of the bit stream input from the input terminal  
 10 into several segments, and converts them into indices  
 5 corresponding to a plurality of decoding parameters.  
 The code input circuit 1010 outputs an index  
 corresponding to LSP (Linear Spectrum Pair) representing  
 the frequency characteristics of the input signal to an  
 LSP decoding circuit 1020. The circuit 1010 outputs an  
 10 index corresponding to a delay  $L_{pd}$  representing the pitch  
 period of the input signal to a pitch signal decoding  
 circuit 1210, and an index corresponding to a sound  
 source vector made up of a random number and a pulse to  
 a sound source signal decoding circuit 1110. The  
 15 circuit 1010 outputs an index corresponding to the first  
 gain to a first gain decoding circuit 1220, and an index  
 corresponding to the second gain to a second gain  
 decoding circuit 1120.

The LSP decoding circuit 1020 has a table  
 20 which stores a plurality of sets of LSPs. The LSP  
 decoding circuit 1020 receives the index output from the  
 code input circuit 1010, reads an LSP corresponding to  
 the index from the table, and sets the LSP as  $LSP\hat{q}_j^{(N_{sfr})}(n)$ ,  
 $j = 1, \Lambda, N_p$  in the  $N_{sfr}$ th subframe of the current frame  
 25 (nth frame).  $N_p$  is a linear prediction order. The LSPs  
 of the first to  $(N_{sfr}-1)$ th subframes are obtained by  
 linearly interpolating  $\hat{q}_j^{(N_{sfr})}(n)$  and  $\hat{q}_j^{(N_{sfr})}(n-1)$ .  $LSP\hat{q}_j^{(m)}(n)$ ,

$j = 1, \Lambda, N_p$ ,  $m = 1, \Lambda, N_{sfr}$  are output to a linear prediction coefficient conversion circuit 1030 and smoothing coefficient calculation circuit 1310.

The linear prediction coefficient conversion  
5 circuit 1030 receives  $LSP\hat{q}_j^{(m)}(n)$ ,  $j = 1, \Lambda, N_p$ ,  $m = 1, \Lambda, N_{sfr}$  output from the LSP decoding circuit 1020. The linear prediction coefficient conversion circuit 1030 converts the received  $\hat{q}_j^{(m)}(n)$  into a linear prediction coefficient  $\hat{\alpha}_j^{(m)}(n)$ ,  $j = 1, \Lambda, N_p$ ,  $m = 1, \Lambda, N_{sfr}$ , and outputs  $\hat{\alpha}_j^{(m)}(n)$  to a  
10 synthesis filter 1040. Conversion of the LSP into the linear prediction coefficient can adopt a known method, e.g., a method described in Section 5.2.4 of reference 2.

The sound source signal decoding circuit 1110 has a table which stores a plurality of sound source  
15 vectors. The sound source signal decoding circuit 1110 receives the index output from the code input circuit 1010, reads a sound source vector corresponding to the index from the table, and outputs the vector to a second gain circuit 1130.

20 The second gain decoding circuit 1120 has a table which stores a plurality of gains. The second gain decoding circuit 1120 receives the index output from the code input circuit 1010, reads a second gain corresponding to the index from the table, and outputs  
25 the second gain to a smoothing circuit 1320.

The second gain circuit 1130 receives the first sound source vector output from the sound source

signal decoding circuit 1110 and the second gain output from the smoothing circuit 1320, multiplies the first sound source vector and the second gain to decode a second sound source vector, and outputs the decoded  
5 second sound source vector to an adder 1050.

A storage circuit 1240 receives and holds an excitation vector from the adder 1050. The storage circuit 1240 outputs an excitation vector which was input and has been held to the pitch signal decoding  
10 circuit 1210.

The pitch signal decoding circuit 1210 receives the past excitation vector held by the storage circuit 1240 and the index output from the code input circuit 1010. The index designates the delay  $L_{pd}$ . The  
15 pitch signal decoding circuit 1210 extracts a vector for  $L_{sfr}$  samples corresponding to the vector length from the start point of the current frame to a past point by  $L_{pd}$  samples in the past excitation vector. Then, the circuit 1210 decodes a first pitch signal (vector). For  
20  $L_{pd} < L_{sfr}$ , the circuit 1210 extracts a vector for  $L_{pd}$  samples, and repetitively couples the extracted  $L_{pd}$  samples to decode the first pitch vector having a vector length of  $L_{sfr}$  samples. The pitch signal decoding circuit 1210 outputs the first pitch vector to a first  
25 gain circuit 1230.

The first gain decoding circuit 1220 has a table which stores a plurality of gains. The first gain

decoding circuit 1220 receives the index output from the code input circuit 1010, reads a first gain corresponding to the index, and outputs the first gain to the first gain circuit 1230.

5           The first gain circuit 1230 receives the first pitch vector output from the pitch signal decoding circuit 1210 and the first gain output from the first gain decoding circuit 1220, multiplies the first pitch vector and the first gain to generate a second pitch  
10 vector, and outputs the generated second pitch vector to the adder 1050.

          The adder 1050 receives the second pitch vector output from the first gain circuit 1230 and the second sound source vector output from the second gain  
15 circuit 1130, adds them, and outputs the sum as an excitation vector to the synthesis filter 1040.

          The smoothing coefficient calculation circuit 1310 receives  $LSP\hat{q}_j^{(m)}(n)$  output from the LSP decoding circuit 1020, and calculates an average  $LSP\bar{q}_{0j}(n)$ :

20           
$$\bar{q}_{0j}(n) = 0.84 \cdot \bar{q}_{0j}(n-1) + 0.16 \cdot \hat{q}_j^{(N_{sfr})}(n)$$

          The smoothing coefficient calculation circuit 1310 calculates an LSP variation amount  $d_0(m)$  for each subframe  $m$ :

$$d_0(m) = \sum_{j=1}^{N_p} \frac{|\bar{q}_{0j}(n) - \hat{q}_j^{(m)}(n)|}{\bar{q}_{0j}(n)}$$

25           The smoothing coefficient calculation circuit 1310 calculates a smoothing coefficient  $k_0(m)$  of the subframe



m:

$$k_0(m) = \min(0.25, \max(0, d_0(m) - 0.4)) / 0.25$$

where  $\min(x, y)$  is a function using a smaller one of  $x$  and  $y$ , and  $\max(x, y)$  is a function using a larger one of  $x$  and  $y$ . The smoothing coefficient calculation circuit 1310 outputs the smoothing coefficient  $k_0(m)$  to the smoothing circuit 1320.

The smoothing circuit 1320 receives the smoothing coefficient  $k_0(m)$  output from the smoothing coefficient calculation circuit 1310 and the second gain output from the second gain decoding circuit 1120. The smoothing circuit 1320 calculates an average gain  $\bar{g}_0(m)$  from a second gain  $\hat{g}_0(m)$  of the subframe  $m$  by

$$\bar{g}_0(m) = \frac{1}{5} \sum_{i=0}^4 \hat{g}_0(m - i)$$

The second gain  $\hat{g}_0(m)$  is replaced by

$$\hat{g}_0(m) = \hat{g}_0(m) \cdot k_0(m) + \bar{g}_0(m) \cdot (1 - k_0(m))$$

The smoothing circuit 1320 outputs the second gain  $\hat{g}_0(m)$  to the second gain circuit 1130.

The synthesis filter 1040 receives the excitation vector output from the adder 1050 and a linear prediction coefficient  $\alpha_i$ ,  $i = 1, \Lambda, N_p$  output from the linear prediction coefficient conversion circuit 1030. The synthesis filter 1040 calculates a reconstructed vector by driving the synthesis filter  $1/A(z)$  in which the linear prediction coefficient is set, by the excitation vector. Then, the synthesis filter

1040 outputs the reconstructed vector from an output terminal 20. Letting  $\alpha_i$ ,  $i = 1, \Lambda, N_p$  be the linear prediction coefficient, the transfer function  $1/A(z)$  of the synthesis filter is given by

5 
$$1 / (A)z = 1 / (1 - \sum_{i=1}^{N_p} \alpha_i z^i)$$

Fig. 5 shows the arrangement of a speech signal encoding apparatus in a conventional speech signal encoding/decoding apparatus. A first gain circuit 1230, second gain circuit 1130, adder 1050, and  
10 storage circuit 1240 are the same as the blocks described in the conventional speech signal decoding apparatus in Fig. 4, and a description thereof will be omitted.

An input signal (input vector) generated by  
15 sampling a speech signal and combining a plurality of samples as one frame into one vector is input from an input terminal 30. A linear prediction coefficient calculation circuit 5510 receives the input vector from the input terminal 30. The linear prediction  
20 coefficient calculation circuit 5510 performs linear prediction analysis for the input vector to obtain a linear prediction coefficient. Linear prediction analysis is described in Chapter 8 "Linear Predictive Coding of Speech" of reference 4.

25 The linear prediction coefficient calculation circuit 5510 outputs the linear prediction coefficient

to an LSP conversion/quantization circuit 5520,  
weighting filter 5050, and weighting synthesis filter  
5040.

The LSP conversion/quantization circuit 5520  
5 receives the linear prediction coefficient output from  
the linear prediction coefficient calculation circuit  
5510, converts the linear prediction coefficient into  
LSP, and quantizes the LSP to attain the quantized LSP.  
Conversion of the linear prediction coefficient into the  
10 LSP can adopt a known method, e.g., a method described  
in Section 5.2.4 of reference 2.

Quantization of the LSP can adopt a method  
described in Section 5.2.5 of reference 2. As described  
in the LSP decoding circuit of Fig. 4 (prior art), the  
15 quantized LSP is the quantized  $LSP\hat{q}_j^{(N_{sfr})}(n)$ ,  $j = 1, \Lambda, N_p$  in  
the  $N_{sfr}$  subframe of the current frame (nth frame). The  
quantized LSPs of the first to  $(N_{sfr}-1)$ th subframes are  
obtained by linearly interpolating  $\hat{q}_j^{(N_{sfr})}(n)$  and  
 $\hat{q}_j^{(N_{sfr})}(n-1)$ . The LSP is  $LSPq_j^{(N_{sfr})}(n)$ ,  $j = 1, \Lambda, N_p$  in the  
20  $N_{sfr}$  subframe of the current frame (nth frame). The LSPs  
of the first to  $(N_{sfr}-1)$ th subframes are obtained by  
linearly interpolating  $q_j^{(N_{sfr})}(n)$  and  $q_j^{(N_{sfr})}(n-1)$ .

The LSP conversion/quantization circuit 5520  
outputs the  $LSPq_j^{(m)}(n)$ ,  $j = 1, \Lambda, N_p$ ,  $m = 1, \Lambda, N_{sfr}$ , and the  
25 quantized  $LSP\hat{q}_j^{(m)}(n)$ ,  $j = 1, \Lambda, N_p$ ,  $m = 1, \Lambda, N_{sfr}$  to a linear  
prediction coefficient conversion circuit 5030, and an  
index corresponding to the quantized  $LSP\hat{q}_j^{(N_{sfr})}(n)$ ,  $j =$

1,  $\Lambda$ ,  $N_p$  to a code output circuit 6010.

The linear prediction coefficient conversion circuit 5030 receives the  $LSPq_j^{(m)}(n)$ ,  $j = 1, \Lambda, N_p$ ,  $m = 1, \Lambda, N_{sfr}$ , and the quantized  $LSP\hat{q}_j^{(m)}(n)$ ,  $j = 1, \Lambda, N_p$ ,  $m =$

5  $1, \Lambda, N_{sfr}$  output from the LSP conversion/quantization circuit 5520. The circuit 5030 converts  $q_j^{(m)}(n)$  into a linear prediction coefficient  $\alpha_j^{(m)}(n)$ ,  $j = 1, \Lambda, N_p$ ,  $m = 1, \Lambda, N_{sfr}$ , and  $\hat{q}_j^{(m)}(n)$  into a quantized linear prediction coefficient  $\hat{\alpha}_j^{(m)}(n)$ ,  $j = 1, \Lambda, N_p$ ,  $m = 1, \Lambda, N_{sfr}$ . The linear  
10 prediction coefficient conversion circuit 5030 outputs the  $\alpha_j^{(m)}(n)$  to the weighting filter 5050 and weighting synthesis filter 5040, and  $\hat{\alpha}_j^{(m)}(n)$  to the weighting synthesis filter 5040. Conversion of the LSP into the linear prediction coefficient and conversion of the  
15 quantized LSP into the quantized linear prediction coefficient can adopt a known method, e.g., a method described in Section 5.2.4 of reference 2.

The weighting filter 5050 receives the input vector from the input terminal 30 and the linear  
20 prediction coefficient output from the linear prediction coefficient conversion circuit 5030, and generates a weighting filter  $W(z)$  corresponding to the human sense of hearing using the linear prediction coefficient. The weighting filter is driven by the input vector to obtain  
25 a weighted input vector. The weighting filter 5050 outputs the weighted input vector to a subtractor 5060. The transfer function  $W(z)$  of the weighting filter 5050

is given by  $W(z) = Q(z/\gamma_1)/Q(z/\gamma_2)$ .

$$\text{Note that } Q(z/\gamma_1) = 1 - \sum_{i=1}^{N_p} \alpha_i^{(m)} \gamma_1^i z^i \text{ and } Q(z/\gamma_2) \\ = 1 - \sum_{i=1}^{N_p} \alpha_i^{(m)} \gamma_2^i z^i \text{ where } \gamma_1 \text{ and } \gamma_2 \text{ are constants, e.g., } \gamma_1 =$$

0.9 and  $\gamma_2 = 0.6$ . Details of the weighting filter are  
5 described in reference 1.

The weighting synthesis filter 5040 receives  
the excitation vector output from the adder 1050, and  
the linear prediction coefficient  $\alpha_j^{(m)}(n)$ ,  $j = 1, \Lambda, N_p$ ,  $m =$   
1,  $\Lambda, N_{sfr}$ , and the quantized linear prediction coefficient  
10  $\hat{\alpha}_j^{(m)}(n)$ ,  $j = 1, \Lambda, N_p$ ,  $m = 1, \Lambda, N_{sfr}$  that are output from the  
linear prediction coefficient conversion circuit 5030.

A weighting synthesis filter  $H(z)W(z) = Q(z/\gamma_1)/[A(z)Q(z/\gamma_2)]$  having  $\alpha_j^{(m)}(n)$  and  $\hat{\alpha}_j^{(m)}(n)$  is driven by the  
excitation vector to obtain a weighted reconstructed  
15 vector. The transfer function  $H(z) = 1/A(z)$  of the  
synthesis filter is given by  $1/A(z) = 1/(1 - \sum_{i=1}^{N_p} \hat{\alpha}_i^{(m)} z^i)$ .

The subtractor 5060 receives the weighted  
input vector output from the weighting filter 5050 and  
the weighted reconstructed vector output from the  
20 weighting synthesis filter 5040, calculates their  
difference, and outputs it as a difference vector to a  
minimizing circuit 5070.

The minimizing circuit 5070 sequentially  
outputs all indices corresponding to sound source  
25 vectors stored in a sound source signal generation

circuit 5110 to the sound source signal generation  
circuit 5110. The minimizing circuit 5070 sequentially  
outputs indices corresponding to all delays  $L_{pd}$  within a  
range defined by a pitch signal generation circuit 5210  
5 to the pitch signal generation circuit 5210. The  
minimizing circuit 5070 sequentially outputs indices  
corresponding to all first gains stored in a first gain  
generation circuit 6220 to the first gain generation  
circuit 6220, and indices corresponding to all second  
10 gains stored in a second gain generation circuit 6120 to  
the second gain generation circuit 6120.

The minimizing circuit 5070 sequentially  
receives difference vectors output from the subtractor  
5060, calculates their norms, selects a sound source  
15 vector, delay  $L_{pd}$ , and first and second gains that  
minimize the norm, and outputs corresponding indices to  
the code output circuit 6010. The pitch signal  
generation circuit 5210, sound source signal generation  
circuit 5110, first gain generation circuit 6220, and  
20 second gain generation circuit 6120 sequentially receive  
indices output from the minimizing circuit 5070.

The pitch signal generation circuit 5210,  
sound source signal generation circuit 5110, first gain  
generation circuit 6220, and second gain generation  
25 circuit 6120 are the same as the pitch signal decoding  
circuit 1210, sound source signal decoding circuit 1110,  
first gain decoding circuit 1220, and second gain

decoding circuit 1120 in Fig. 4 except for input/output connections, and a detailed description of these blocks will be omitted.

The code output circuit 6010 receives an index  
5 corresponding to the quantized LSP output from the LSP conversion/quantization circuit 5520, and indices corresponding to the sound source vector, delay  $L_{pd}$ , and first and second gains that are output from the minimizing circuit 5070. The code output circuit 6010  
10 converts these indices into a bit stream code, and outputs it via an output terminal 40.

The first problem is that sound different from normal voiced speech is generated in short unvoiced speech intermittently contained in the voiced speech or  
15 part of the voiced speech. As a result, discontinuous sound is generated in the voiced speech. This is because the LSP variation amount  $d_0(m)$  decreases in the short unvoiced speech to increase the smoothing coefficient. Since  $d_0(m)$  greatly varies over time,  $d_0(m)$   
20 exhibits a large value to a certain degree in part of the voiced speech, but the smoothing coefficient does not become 0.

The second problem is that the smoothing coefficient abruptly changes in unvoiced speech. As a  
25 result, discontinuous sound is generated in the unvoiced speech. This is because the smoothing coefficient is determined using  $d_0(m)$  which greatly varies over time.

The third problem is that proper smoothing processing corresponding to the type of background noise cannot be selected. As a result, the decoding quality degrades. This is because the decoding parameter is  
5 smoothed based on a single algorithm using only different set parameters.

#### Summary of the Invention

It is an object of the present invention to provide a speech signal decoding method and apparatus  
10 for improving the quality of reconstructed speech against background noise speech.

To achieve the above object, according to the present invention, there is provided a speech signal decoding method comprising the steps of decoding  
15 information containing at least a sound source signal, a gain, and filter coefficients from a received bit stream, identifying voiced speech and unvoiced speech of a speech signal using the decoded information, performing smoothing processing based on the decoded information  
20 for at least either one of the decoded gain and the decoded filter coefficients in the unvoiced speech, and decoding the speech signal by driving a filter having the decoded filter coefficients by an excitation signal obtained by multiplying the decoded sound source signal  
25 by the decoded gain using a result of the smoothing processing.



### Brief Description of the Drawings

Fig. 1 is a block diagram showing a speech signal decoding apparatus according to the first embodiment of the present invention;

5 Fig. 2 is a block diagram showing a speech signal decoding apparatus according to the second embodiment of the present invention;

Fig. 3 is a block diagram showing a speech signal encoding apparatus used in the present invention;

10 Fig. 4 is a block diagram showing a conventional speech signal decoding apparatus; and

Fig. 5 is a block diagram showing a conventional speech signal encoding apparatus.

### Description of the Preferred Embodiments

15 The present invention will be described in detail below with reference to the accompanying drawings.

Fig. 1 shows a speech signal decoding apparatus according to the first embodiment of the present invention. An input terminal 10, output  
20 terminal 20, LSP decoding circuit 1020, linear prediction coefficient conversion circuit 1030, sound source signal decoding circuit 1110, storage circuit 1240, pitch signal decoding circuit 1210, first gain circuit 1230, second gain circuit 1130, adder 1050, and  
25 synthesis filter 1040 are the same as the blocks described in the prior art of Fig. 4, and a description thereof will be omitted.

A code input circuit 1010, voiced/unvoiced identification circuit 2020, noise classification circuit 2030, first switching circuit 2110, second switching circuit 2210, first filter 2150, second filter 2160, third filter 2170, fourth filter 2250, fifth filter 2260, sixth filter 2270, first gain decoding circuit 2220, and second gain decoding circuit 2120 will be described.

A bit stream is input at a period (frame) of  $T_{fr}$  msec (e.g., 20 msec), and a reconstructed vector is calculated at a period (subframe) of  $T_{fr}/N_{sfr}$  msec (e.g., 5 msec) for an integer  $N_{sfr}$  (e.g., 4). The frame length is given by  $L_{fr}$  samples (e.g., 320 samples), and the subframe length is given by  $L_{sfr}$  samples (e.g., 80 samples). These numbers of samples are determined by the sampling frequency (e.g., 16 kHz) of an input signal. Each block will be described.

The code input circuit 1010 segments the code of a bit stream input from an input terminal 10 into several segments, and converts them into indices corresponding to a plurality of decoding parameters. The code input circuit 1010 outputs an index corresponding to LSP to the LSP decoding circuit 1020. The circuit 1010 outputs an index corresponding to a speech mode to a speech mode decoding circuit 2050, an index corresponding to a frame energy to a frame power decoding circuit 2040, an index corresponding to a delay

$L_{pd}$  to the pitch signal decoding circuit 1210, and an index corresponding to a sound source vector to the sound source signal decoding circuit 1110. The circuit 1010 outputs an index corresponding to the first gain to the first gain decoding circuit 2220, and an index corresponding to the second gain to the second gain decoding circuit 2120.

The speech mode decoding circuit 2050 receives the index corresponding to the speech mode that is output from the code input circuit 1010, and sets a speech mode  $S_{mode}$  corresponding to the index. The speech mode is determined by threshold processing for an intra-frame average  $\overline{G}_{op}(n)$  of an open-loop pitch prediction gain  $G_{op}(m)$  calculated using a perceptually weighted input signal in a speech encoder. The speech mode is transmitted to the decoder. In this case,  $n$  represents the frame number; and  $m$ , the subframe number. Determination of the speech mode is described in K. Ozawa et al., "M-LCELP Speech Coding at 4 kb/s with Multi-Mode and Multi-Codebook", IEICE Trans. On Commun., Vol. E77-B, No. 9, pp. 1114 - 1121, September 1994 (reference 3).

The speech mode decoding circuit 2050 outputs the speech mode  $S_{mode}$  to the voiced/unvoiced identification circuit 2020, first gain decoding circuit 2220, and second gain decoding circuit 2120.

The frame power decoding circuit 2040 has a

table 2040a which stores a plurality of frame energies.  
The frame power decoding circuit 2040 receives the index  
corresponding to the frame power that is output from the  
code input circuit 1010, and reads a frame power  $\hat{E}_{rms}$

5 corresponding to the index from the table 2040a. The  
frame power is attained by quantizing the power of an  
input signal in the speech encoder, and an index  
corresponding to the quantized value is transmitted to  
the decoder. The frame power decoding circuit 2040  
10 outputs the frame power  $\hat{E}_{rms}$  to the voiced/unvoiced  
identification circuit 2020, first gain decoding circuit  
2220, and second gain decoding circuit 2120.

The voiced/unvoiced identification circuit  
2020 receives  $LSP\hat{q}_j^{(m)}(n)$  output from the LSP decoding  
15 circuit 1020, the speech mode  $S_{mode}$  output from the  
speech mode decoding circuit 2050, and the frame power  
 $\hat{E}_{rms}$  output from the frame power decoding circuit 2040.  
The sequence of obtaining the variation amount of a  
spectral parameter will be explained.

20 As the spectral parameter,  $LSP\hat{q}_j^{(m)}(n)$  is used.  
In the  $n$ th frame, a long-term average  $\bar{q}_j(n)$  of the LSP is  
calculated by

$$\bar{q}_j(n) = \beta_0 \cdot \bar{q}_j(n-1) + (1 - \beta_0) \cdot \hat{q}_j^{(N_{sfr})}(n), j = 1, \Lambda, N_p$$

where  $\beta_0 = 0.9$ .

25 A variation amount  $d_q(n)$  of the LSP in the  $n$ th  
frame is defined by

$$d_q(n) = \sum_{j=1}^{N_p} \sum_{m=1}^{N_{\text{eff}}} \frac{D_{q,j}^{(m)}(n)}{\bar{q}_j(n)}$$

where  $D_{q,j}^{(m)}(n)$  corresponds to the distance between  $\bar{q}_j(n)$  and  $\hat{q}_j^{(m)}(n)$ . For example,

$$D_{q,j}^{(m)}(n) = (\bar{q}_j(n) - \hat{q}_j^{(m)}(n))^2$$

5 or

$$D_{q,j}^{(m)}(n) = |\bar{q}_j(n) - \hat{q}_j^{(m)}(n)|$$

In this case,  $D_{q,j}^{(m)}(n) = |\bar{q}_j(n) - \hat{q}_j^{(m)}(n)|$  is employed.

A section where the variation amount  $d_q(n)$  is large substantially corresponds to voiced speech, whereas a section where the variation amount  $d_q(n)$  is small substantially corresponds to unvoiced speech. However, the variation amount  $d_q(n)$  greatly varies over time, and the range of  $d_q(n)$  in voiced speech and that in unvoiced speech overlap each other. Thus, a threshold for identifying voiced speech and unvoiced speech is difficult to set.

For this reason, the long-term average of  $d_q(n)$  is used to identify voiced speech and unvoiced speech. A long-term average  $\bar{d}_{q1}(n)$  of  $d_q(n)$  is calculated using a linear or non-linear filter. As  $\bar{d}_{q1}(n)$ , the average, median, or mode of  $d_q(n)$  can be applied. In this case,

$$\bar{d}_{q1}(n) = \beta_1 \cdot \bar{d}_{q1}(n-1) + (1 - \beta_1) \cdot d_q(n)$$

is used where  $\beta_1 = 0.9$ .

Threshold processing for  $\bar{d}_{q1}(n)$  determines an identification flag  $S_{vs}$ :

if ( $\bar{d}_{q1}(n) \geq C_{th1}$ ) then  $S_{vs} = 1$

else  $S_{vs} = 0$

where  $C_{th1}$  is a given constant (e.g., 2.2),  $S_{vs} = 1$

corresponds to voiced speech, and  $S_{vs} = 0$  corresponds to

5 unvoiced speech.

Even voiced speech may be mistaken for

unvoiced speech in a section where steadiness is high

because  $d_q(n)$  is small. To avoid this, a section where

the frame power and pitch prediction gain are large is

10 regarded as voiced speech. For  $S_{vs} = 0$ ,  $S_{vs}$  is corrected  
by the following additional determination:

if ( $\hat{E}_{rms} \geq C_{rms}$  and  $S_{mode} \geq 2$ ) then  $S_{vs} = 1$

else  $S_{vs} = 0$

where  $C_{rms}$  is a given constant (e.g., 10,000), and  $S_{mode} \geq$

15 2 corresponds to an intra-frame average  $\bar{G}_{op}(n)$  of 3.5 dB

or more for the pitch prediction gain.

This is defined by the encoder.

The voiced/unvoiced identification circuit

2020 outputs  $S_{vs}$  to the noise classification circuit 2030,

20 first switching circuit 2110, and second switching

circuit 2210, and  $\bar{d}_{q1}(n)$  to the noise classification

circuit 2030.

The noise classification circuit 2030 receives

$\bar{d}_{q1}(n)$  and  $S_{vs}$  that are output from the voiced/unvoiced

25 identification circuit 2020. In unvoiced speech (noise),

a value  $\bar{d}_{q2}(n)$  which reflects the average behavior of

$\bar{d}_{q1}(n)$  is obtained using a linear or non-linear filter.

For  $S_{vs} = 0$ ,

$$\bar{d}_{q2}(n) = \beta_2 \cdot \bar{d}_{q2}(n-1) + (1 - \beta_2) \cdot \bar{d}_{q1}(n)$$

is calculated for  $\beta_2 = 0.94$ .

Threshold processing for  $\bar{d}_{q2}(n)$  classifies

5 noise to determine a classification flag  $S_{nz}$ :

if ( $\bar{d}_{q2}(n) \geq C_{th2}$ ) then  $S_{nz} = 1$

else  $S_{nz} = 0$

where  $C_{th2}$  is a given constant (e.g., 1.7),  $S_{nz} = 1$

corresponds to noise whose frequency characteristics

10 unsteadily change over time, and  $S_{nz} = 0$  corresponds to

noise whose frequency characteristics steadily change

over time. The noise classification circuit 2030

outputs  $S_{nz}$  to the first and second switching circuits

2110 and 2210.

15 The first switching circuit 2110 receives  $LSP\hat{q}_j^{(m)}(n)$  output from the LSP decoding circuit 1020, the identification flag  $S_{vs}$  output from the voiced/unvoiced identification circuit 2020, and the classification flag  $S_{nz}$  output from the noise classification circuit 2030.

20 The first switching circuit 2110 is switched in accordance with the identification and classification flag values to output  $LSP\hat{q}_j^{(m)}(n)$  to the first filter 2150 for  $S_{vs} = 0$  and  $S_{nz} = 0$ , to the second filter 2160 for  $S_{vs} = 0$  and  $S_{nz} = 1$ , and to the third filter 2170 for  $S_{vs} = 1$ .

25 The first filter 2150 receives  $LSP\hat{q}_j^{(m)}(n)$  output from the first switching circuit 2110, smoothes it using a linear or non-linear filter, and outputs it as a first

smoothed  $LSP\bar{q}_{1,j}^{(m)}(n)$  to the linear prediction coefficient conversion circuit 1030. In this case, the first filter 2150 uses a filter given by

$$\bar{q}_{1,j}^{(m)}(n) = \gamma_1 \cdot \bar{q}_{1,j}^{(m-1)}(n) + (1 - \gamma_1) \cdot \hat{q}_j^{(m)}(n), j = 1, \Lambda, N_p$$

5 where  $\bar{q}_{1,j}^{(0)}(n) = \bar{q}_{1,j}^{(N_{sfr})}(n-1)$ , and  $\gamma_1 = 0.5$ .

The second filter 2160 receives  $LSP\hat{q}_j^{(m)}(n)$

output from the first switching circuit 2110, smoothes it using a linear or non-linear filter, and outputs it as a second smoothed  $LSP\bar{q}_{2,j}^{(m)}(n)$  to the linear prediction

10 coefficient conversion circuit 1030. In this case, the second filter 2160 uses a filter given by

$$\bar{q}_{2,j}^{(m)}(n) = \gamma_2 \cdot \bar{q}_{2,j}^{(m-1)}(n) + (1 - \gamma_2) \cdot \hat{q}_j^{(m)}(n), j = 1, \Lambda, N_p$$

where  $\bar{q}_{2,j}^{(0)}(n) = \bar{q}_{2,j}^{(N_{sfr})}(n-1)$ , and  $\gamma_2 = 0.0$ .

The third filter 2170 receives  $LSP\hat{q}_j^{(m)}(n)$  output

15 from the first switching circuit 2110, smoothes it using a linear or non-linear filter, and outputs it as a third smoothed  $LSP\bar{q}_{3,j}^{(m)}(n)$  to the linear prediction coefficient conversion circuit 1030. In this case,  $\bar{q}_{3,j}^{(m)}(n) = \hat{q}_j^{(m)}(n)$ .

The second switching circuit 2210 receives the  
20 second gain  $\hat{g}_2^{(m)}(n)$  output from the second gain decoding circuit 2120, the identification flag  $S_{vs}$  output from the voiced/unvoiced identification circuit 2020, and the classification flag  $S_{nz}$  output from the noise classification circuit 2030. The second switching  
25 circuit 2210 is switched in accordance with the identification and classification flag values to output the second gain  $\hat{g}_2^{(m)}(n)$  to the fourth filter 2250 for  $S_{vs} =$



0 and  $S_{nz} = 0$ , to the fifth filter 2260 for  $S_{vs} = 0$  and  $S_{nz} = 1$ , and to the sixth filter 2270 for  $S_{vs} = 1$ .

The fourth filter 2250 receives the second gain  $\hat{g}_2^{(m)}(n)$  output from the second switching circuit 2210, smoothes it using a linear or non-linear filter, and outputs it as a first smoothed gain  $\overline{g}_{2,1}^{(m)}(n)$  to the second gain circuit 1130. In this case, the fourth filter 2250 uses a filter given by

$$\overline{g}_{2,1}^{(m)}(n) = \gamma_2 \cdot \overline{g}_{2,1}^{(m-1)}(n) + (1 - \gamma_2) \cdot \hat{g}_2^{(m)}(n)$$

10 where  $\overline{g}_{2,1}^{(0)}(n) = \overline{g}_{2,1}^{(N_{sfr})}(n-1)$ , and  $\gamma_2 = 0.9$ .

The fifth filter 2260 receives the second gain  $\hat{g}_2^{(m)}(n)$  output from the second switching circuit 2210, smoothes it using a linear or non-linear filter, and outputs it as a second smoothed gain  $\overline{g}_{2,2}^{(m)}(n)$  to the second gain circuit 1130. In this case, the fifth filter 2260 uses a filter given by

$$\overline{g}_{2,2}^{(m)}(n) = \gamma_2 \cdot \overline{g}_{2,2}^{(m-1)}(n) + (1 - \gamma_2) \cdot \hat{g}_2^{(m)}(n)$$

where  $\overline{g}_{2,2}^{(0)}(n) = \overline{g}_{2,2}^{(N_{sfr})}(n-1)$ , and  $\gamma_2 = 0.9$ .

The sixth filter 2270 receives the second gain  $\hat{g}_2^{(m)}(n)$  output from the second switching circuit 2210, smoothes it using a linear or non-linear filter, and outputs it as a third smoothed gain  $\overline{g}_{2,3}^{(m)}(n)$  to the second gain circuit 1130. In this case,  $\overline{g}_{2,3}^{(m)}(n) = \hat{g}_2^{(m)}(n)$ .

The first gain decoding circuit 2220 has a table 2220a which stores a plurality of gains. The first gain decoding circuit 2220 receives an index corresponding to the third gain output from the code

input circuit 1010, the speech mode  $S_{\text{mode}}$  output from the speech mode decoding circuit 2050, the frame power  $\hat{E}_{\text{rms}}$  output from the frame power decoding circuit 2040, the linear prediction coefficient  $\hat{\alpha}_j^{(m)}(n)$ ,  $j = 1, \Lambda, N_p$  of the  
 5 mth subframe of the nth frame output from the linear prediction coefficient conversion circuit 1030, and a pitch vector  $c_{\text{ac}}(i)$ ,  $i = 1, \Lambda, L_{\text{sfr}}$  output from the pitch signal decoding circuit 1210.

The first gain decoding circuit 2220  
 10 calculates a k parameter  $k_j^{(m)}(n)$ ,  $j = 1, \Lambda, N_p$  (to be simply represented as  $k_j$ ) from the linear prediction coefficient  $\hat{\alpha}_j^{(m)}(n)$ . This is calculated by a known method, e.g., a method described in Section 8.3.2 in L.R. Rabiner et al., "Digital Processing of Speech Signals",  
 15 Prentice-Hall, 1978 (reference 4). Then, the first gain decoding circuit 2220 calculates an estimated residual power  $\tilde{E}_{\text{res}}$  using  $k_j$ :

$$\tilde{E}_{\text{res}} = \hat{E}_{\text{rms}} \sqrt{\prod_{j=1}^{N_p} (1 - k_j^2)}$$

The first gain decoding circuit 2220 reads a  
 20 third gain  $\hat{\gamma}_{\text{gac}}$  corresponding to the index from the table 2220a switched by the speech mode  $S_{\text{mode}}$ , and calculates a first gain  $\hat{g}_{\text{ac}}$ :

$$\hat{g}_{\text{ac}} = \hat{\gamma}_{\text{gac}} \frac{\tilde{E}_{\text{res}}}{\sqrt{\sum_{i=0}^{L_{\text{sfr}}-1} c_{\text{ac}}^2(i)}}$$

The first gain decoding circuit 2220 outputs  
 25 the first gain  $\hat{g}_{\text{ac}}$  to the first gain circuit 1230. The second gain decoding circuit 2120 has a table 2120a

which stores a plurality of gains.

The second gain decoding circuit 2120 receives an index corresponding to the fourth gain output from the code input circuit 1010, the speech mode  $S_{\text{mode}}$  output from the speech mode decoding circuit 2050, the frame power  $\hat{E}_{\text{rms}}$  output from the frame power decoding circuit 2040, the linear prediction coefficient  $\hat{\alpha}_j^{(m)}(n)$ ,  $j = 1, \Lambda, N_p$  of the  $m$ th subframe of the  $n$ th frame output from the linear prediction coefficient conversion circuit 1030, and a sound source vector  $c_{\text{ec}}(i)$ ,  $i = 1, \Lambda, L_{\text{sfr}}$  output from the sound source signal decoding circuit 1110.

The second gain decoding circuit 2120 calculates a  $k$  parameter  $k_j^{(m)}(n)$ ,  $j = 1, \Lambda, N_p$  (to be simply represented as  $k_j$ ) from the linear prediction coefficient  $\hat{\alpha}_j^{(m)}(n)$ . This is calculated by the same known method as described for the first gain decoding circuit 2220. Then, the second gain decoding circuit 2120 calculates an estimated residual power  $\tilde{E}_{\text{res}}$  using  $k_j$ :

$$\tilde{E}_{\text{res}} = \hat{E}_{\text{rms}} \sqrt{\prod_{j=1}^{N_p} (1 - k_j^2)}$$

The second gain decoding circuit 2120 reads a fourth gain  $\hat{\gamma}_{\text{gec}}$  corresponding to the index from the table 2120a switched by the speech mode  $S_{\text{mode}}$ , and calculates a second gain  $\hat{g}_{\text{ec}}$ :

$$\hat{g}_{\text{ec}} = \hat{\gamma}_{\text{gec}} \frac{\tilde{E}_{\text{res}}}{\sqrt{\sum_{i=0}^{L_{\text{sfr}}-1} c_{\text{ec}}^2(i)}}$$

The second gain decoding circuit 2120 outputs

the second gain  $\hat{g}_{ec}$  to the second switching circuit 2210.

Fig. 2 shows a speech signal decoding apparatus according to the second embodiment of the present invention.

5            This speech signal decoding apparatus of the present invention is implemented by replacing the frame power decoding circuit 2040 in the first embodiment with a power calculation circuit 3040, the speech mode  
10       decoding circuit 2050 with a speech mode determination circuit 3050, the first gain decoding circuit 2220 with a first gain decoding circuit 1220, and the second gain decoding circuit 2120 with second gain decoding circuit 1120. In this arrangement, the frame power and speech mode are not encoded and transmitted in the encoder, and  
15       the frame power (power) and speech mode are obtained using parameters used in the decoder.

          The first and second gain decoding circuits 1220 and 1120 are the same as the blocks described in the prior art of Fig. 4, and a description thereof will  
20       be omitted.

          The power calculation circuit 3040 receives a reconstructed vector output from a synthesis filter 1040, calculates a power from the sum of squares of the reconstructed vectors, and outputs the power to a  
25       voiced/unvoiced identification circuit 2020. In this case, the power is calculated for each subframe. Calculation of the power in the mth subframe uses a

reconstructed signal output from the synthesis filter 1040 in the (m-1)th subframe. For a reconstructed signal  $S_{\text{syn}}(i)$ ,  $i = 0, \Lambda, L_{\text{sfr}}$ , the power  $E_{\text{rms}}$  is calculated by, e.g., RMS (Root Mean Square):

$$5 \quad E_{\text{rms}} = \sqrt{\sum_{i=0}^{L_{\text{sfr}}-1} S_{\text{syn}}^2(i)}$$

The speech mode determination circuit 3050 receives a past excitation vector  $e_{\text{mem}}(i)$ ,  $i = 0, \Lambda, L_{\text{mem}}-1$  held by a storage circuit 1240, and the index output from the code input circuit 1010. The index designates  
10 a delay  $L_{\text{pd}}$ .  $L_{\text{mem}}$  is a constant determined by the maximum value of  $L_{\text{pd}}$ .

In the mth subframe, a pitch prediction gain  $G_{\text{emem}}(m)$ ,  $m = 1, \Lambda, N_{\text{sfr}}$  is calculated from the past excitation vector  $e_{\text{mem}}(i)$  and delay  $L_{\text{pd}}$ :

$$15 \quad G_{\text{emem}}(m) = 10 \cdot \log_{10}(g_{\text{emem}}(m))$$

where

$$\begin{aligned} g_{\text{emem}}(m) &= \frac{1}{1 - \frac{E_c^2(m)}{E_{a1}(m)E_{a2}(m)}} \\ E_{a1}(m) &= \sum_{i=0}^{L_{\text{sfr}}-1} e_{\text{mem}}^2(i) \\ E_{a2}(m) &= \sum_{i=0}^{L_{\text{sfr}}-1} e_{\text{mem}}^2(i - L_{\text{pd}}) \\ 20 \quad E_c(m) &= \sum_{i=0}^{L_{\text{sfr}}-1} e_{\text{mem}}(i)e_{\text{mem}}(i - L_{\text{pd}}) \end{aligned}$$

The pitch prediction gain  $G_{\text{emem}}(m)$  or the intra-frame average  $\bar{G}_{\text{emem}}(n)$  in the nth frame of  $G_{\text{emem}}(m)$  undergoes the following threshold processing to set a

speech mode  $S_{\text{mode}}$ :

if  $(\bar{G}_{\text{emem}}(n) \geq 3.5)$  then  $S_{\text{mode}} = 2$

else  $S_{\text{mode}} = 0$

The speech mode determination circuit 3050 outputs the  
5 speech mode  $S_{\text{mode}}$  to the voiced/unvoiced identification  
circuit 2020.

Fig. 3 shows a speech signal encoding  
apparatus used in the present invention.

The speech signal encoding apparatus in Fig. 3  
10 is implemented by adding a frame power calculation  
circuit 5540 and speech mode determination circuit 5550  
in the prior art of Fig. 5, replacing the first and  
second gain generation circuits 6220 and 6120 with first  
and second gain generation circuits 5220 and 5120, and  
15 replacing the code output circuit 6010 with a code  
output circuit 5010. The first and second gain  
generation circuits 5220 and 5120, an adder 1050, and a  
storage circuit 1240 are the same as the blocks  
described in the prior art of Fig. 5, and a description  
20 thereof will be omitted.

The frame power calculation circuit 5540 has a  
table 5540a which stores a plurality of frame energies.  
The frame power calculation circuit 5540 receives an  
input vector from an input terminal 30, calculates the  
25 RMS (Root Mean Square) of the input vector, and  
quantizes the RMS using the table to attain a quantized  
frame power  $\hat{E}_{\text{rms}}$ . For an input vector  $s_i(i)$ ,  $i = 0, \Lambda, L_{\text{sfr}}$ ,

a power  $E_{irms}$  is given by

$$E_{irms} = \sqrt{\sum_{i=0}^{L_{sfr}-1} s_i^2(i)}$$

The frame power calculation circuit 5540  
 outputs the quantized frame power  $\hat{E}_{rms}$  to the first and  
 5 second gain generation circuits 5220 and 5120, and an  
 index corresponding to  $\hat{E}_{rms}$  to the code output circuit  
 5010.

The speech mode determination circuit 5550  
 receives a weighted input vector output from a weighting  
 10 filter 5050.

The speech mode  $S_{mode}$  is determined by  
 executing threshold processing for the intra-frame  
 average  $\bar{G}_{op}(n)$  of an open-loop pitch prediction gain  
 $G_{op}(m)$  calculated using the weighted input vector. In  
 15 this case,  $n$  represents the frame number; and  $m$ , the  
 subframe number.

In the  $m$ th subframe, the following two  
 equations are calculated from a weighted input vector  
 $s_{wi}(i)$  and the delay  $L_{tmp}$ , and  $L_{tmp}$  which maximizes  
 20  $E_{sctmp}^2(m) / E_{sa2tmp}$  is obtained and set as  $L_{op}$ :

$$E_{sctmp}(m) = \sum_{i=0}^{L_{sfr}-1} s_{wi}(i) s_{wi}(i - L_{tmp})$$

$$E_{sa2tmp}(m) = \sum_{i=0}^{L_{sfr}-1} s_{wi}^2(i - L_{tmp})$$

From the weighted input vector  $s_{wi}(i)$  and the  
 delay  $L_{op}$ , the pitch prediction gain  $G_{op}(m)$ ,  $m = 1, \Lambda, N_{sfr}$   
 25 is calculated:

$$G_{op}(m) = 10 \cdot \log_{10}(g_{op}(m))$$

where

where

$$g_{op}(m) = \frac{1}{1 - \frac{E_{sc}^2(m)}{E_{sa1}(m)E_{sa2}(m)}}$$

$$E_{sa1}(m) = \sum_{i=0}^{L_{sfr}-1} s_{wi}^2(i)$$

$$E_{sa2}(m) = \sum_{i=0}^{L_{sfr}-1} s_{wi}^2(i - L_{op})$$

$$E_{sc}(m) = \sum_{i=0}^{L_{sfr}-1} s_{wi}(i)s_{wi}(i - L_{op})$$

The pitch prediction gain  $G_{op}(m)$  or the intra-frame average  $\bar{G}_{op}(n)$  in the  $n$ th frame of  $G_{op}(m)$  undergoes the following threshold processing to set the speech mode

$S_{mode}$ :

if  $(\bar{G}_{op}(n) \geq 3.5)$  then  $S_{mode} = 2$

else  $S_{mode} = 0$

Determination of the speech mode is described in K. Ozawa et al., "M-LCELP Speech Coding at 4 kb/s with Multi-Mode and Multi-Codebook", IEICE Trans. On Commun., Vol. E77-B, No. 9, pp. 1114 - 1121, 1994 (reference 3).

The speech mode determination circuit 5550 outputs the speech mode  $S_{mode}$  to the first and second gain generation circuits 5220 and 5120, and an index corresponding to the speech mode  $S_{mode}$  to the code output circuit 5010.

A pitch signal generation circuit 5210, a



sound source signal generation circuit 5110, and the first and second gain generation circuits 5220 and 5120 sequentially receive indices output from a minimizing circuit 5070. The pitch signal generation circuit 5210,  
5 sound source signal generation circuit 5110, first gain generation circuit 5220, and second gain generation circuit 5120 are the same as the pitch signal decoding circuit 1210, sound source signal decoding circuit 1110, first gain decoding circuit 2220, and second gain  
10 decoding circuit 2120 in Fig. 1 except for input/output connections, and a detailed description of these blocks will be omitted.

The code output circuit 5010 receives an index corresponding to the quantized LSP output from the LSP  
15 conversion/quantization circuit 5520, an index corresponding to the quantized frame power output from the frame power calculation circuit 5540, an index corresponding to the speech mode output from the speech mode determination circuit 5550, and indices  
20 corresponding to the sound source vector, delay  $L_{pd}$ , and first and second gains that are output from the minimizing circuit 5070. The code output circuit 5010 converts these indices into a bit stream code, and outputs it via an output terminal 40.

25 The arrangement of a speech signal encoding apparatus in a speech signal encoding/decoding apparatus according to the fourth embodiment of the present

invention is the same as that of the speech signal encoding apparatus in the conventional speech signal encoding/decoding apparatus, and a description thereof will be omitted.

5                   In the above-described embodiments, the long-term average of  $d_0(m)$  varies over time more gradually than  $d_0(m)$ , and does not intermittently decrease in voiced speech. If the smoothing coefficient is determined in accordance with this average,  
10   discontinuous sound generated in short unvoiced speech intermittently contained in voiced speech can be reduced. By performing identification of voiced or unvoiced speech using the average, the smoothing coefficient of the decoding parameter can be completely set to 0 in  
15   voiced speech.

                  Also for unvoiced speech, using the long-term average of  $d_0(m)$  can prevent the smoothing coefficient from abruptly changing.

                  The present invention smoothes the decoding  
20   parameter in unvoiced speech not by using single processing, but by selectively using a plurality of processing methods prepared in consideration of the characteristics of an input signal. These methods include moving average processing of calculating the  
25   decoding parameter from past decoding parameters within a limited section, auto-regressive processing capable of considering long-term past influence, and non-linear

processing of limiting a preset value by an upper or lower limit after average calculation.

According to the first effect of the present invention, sound different from normal voiced speech  
5 that is generated in short unvoiced speech intermittently contained in voiced speech or part of the voiced speech can be reduced to reduce discontinuous sound in the voiced speech. This is because the long-term average of  $d_0(m)$  which hardly varies over time  
10 is used in the short unvoiced speech, and because voiced speech and unvoiced speech are identified and the smoothing coefficient is set to 0 in the voiced speech.

According to the second effect of the present invention, abrupt changes in smoothing coefficient in  
15 unvoiced speech are reduced to reduce discontinuous sound in the unvoiced speech. This is because the smoothing coefficient is determined using the long-term average of  $d_0(m)$  which hardly varies over time.

According to the third effect of the present invention, smoothing processing can be selected in  
20 accordance with the type of background noise to improve the decoding quality. This is because the decoding parameter is smoothed selectively using a plurality of processing methods in accordance with the  
25 characteristics of an input signal.

What is claimed is:

1. A speech signal decoding method comprising the  
2 steps of:  
3 decoding information containing at least a  
4 sound source signal, a gain, and filter coefficients  
5 from a received bit stream;  
6 identifying voiced speech and unvoiced speech  
7 of a speech signal using the decoded information;  
8 performing smoothing processing based on the  
9 decoded information for at least either one of the  
10 decoded gain and the decoded filter coefficients in the  
11 unvoiced speech; and  
12 decoding the speech signal by driving a filter  
13 having the decoded filter coefficients by an excitation  
14 signal obtained by multiplying the decoded sound source  
15 signal by the decoded gain using a result of the  
16 smoothing processing.
2. A method according to claim 1, wherein  
2 the method further comprises the step of  
3 classifying unvoiced speech in accordance with the  
4 decoded information, and  
5 the step of performing smoothing processing  
6 comprises the step of performing smoothing processing in  
7 accordance with a classification result of the unvoiced  
8 speech for at least either one of the decoded gain and

9 the decoded filter coefficients in the unvoiced speech.

3. A method according to claim 1, wherein the  
2 identifying step comprises the step of performing  
3 identification operation using a value obtained by  
4 averaging for a long term a variation amount based on a  
5 difference between the decoded filter coefficients and  
6 their long-term average.

4. A method according to claim 2, wherein the  
2 classifying step comprises the step of performing  
3 classification operation using a value obtained by  
4 averaging for a long term a variation amount based on a  
5 difference between the decoded filter coefficients and  
6 their long-term average.

5. A method according to claim 1, wherein  
2 the decoding step comprises the step of  
3 decoding information containing pitch periodicity and a  
4 power of the speech signal from the received bit stream,  
5 and  
6 the identifying step comprises the step of  
7 performing identification operation using at least  
8 either one of the decoded pitch periodicity and the  
9 decoded power.

6. A method according to claim 2, wherein

2                   the decoding step comprises the step of  
3 decoding information containing pitch periodicity and a  
4 power of the speech signal from the received bit stream,  
5 and

6                   the classifying step comprises the step of  
7 performing classification operation using at least  
8 either one of the decoded pitch periodicity and the  
9 decoded power.

7.               A method according to claim 1, wherein  
2                   the method further comprises the step of  
3 estimating pitch periodicity and a power of the speech  
4 signal from the excitation signal and the decoded speech  
5 signal, and

6                   the identifying step comprises the step of  
7 performing identification operation using at least  
8 either one of the estimated pitch periodicity  
9 information and the estimated power.

8.               A method according to claim 2, wherein  
2                   the method further comprises the step of  
3 estimating pitch periodicity and a power of the speech  
4 signal from the excitation signal and the decoded speech  
5 signal, and

6                   the classifying step comprises the step of  
7 performing classification operation using at least  
8 either one of the estimated pitch periodicity and the

9 estimated power.

9. A method according to claim 2, wherein the  
2 classifying step comprises the step of classifying  
3 unvoiced speech by comparing a value obtained by the  
4 decoded filter coefficients with a predetermined  
5 threshold.

10. A speech signal decoding apparatus  
2 comprising:  
3 a plurality of decoding means for decoding  
4 information containing at least a sound source signal, a  
5 gain, and filter coefficients from a received bit  
6 stream;  
7 identification means for identifying voiced  
8 speech and unvoiced speech of a speech signal using the  
9 decoded information;  
10 smoothing means for performing smoothing  
11 processing based on the decoded information for at least  
12 either one of the decoded gain and the decoded filter  
13 coefficients in the unvoiced speech identified by said  
14 identification means; and  
15 filter means which has the decoded filter  
16 coefficients and is driven by an excitation signal  
17 obtained by multiplying the decoded sound source signal  
18 by the decoded gain, at least either one of the decoded  
19 filter coefficients and the decoded gain using an output

20 result of said smoothing means.

11. An apparatus according to claim 10, wherein  
2 said apparatus further comprises  
3 classification means for classifying unvoiced speech in  
4 accordance with the decoded information, and  
5 said smoothing means performs smoothing  
6 processing in accordance with a classification result of  
7 said classification means for at least either one of the  
8 decoded gain and the decoded filter coefficients in the  
9 unvoiced speech identified by said identification means.

12. An apparatus according to claim 10, wherein  
2 said identification means performs identification  
3 operation using a value obtained by averaging for a long  
4 term a variation amount based on a difference between  
5 the decoded filter coefficients and their long-term  
6 average.

13. An apparatus according to claim 11, wherein  
2 said classification means performs classification  
3 operation using a value obtained by averaging for a long  
4 term a variation amount based on a difference between  
5 the decoded filter coefficients and their long-term  
6 average.

14. An apparatus according to claim 10, wherein



2           said decoding means decodes information  
3 containing pitch periodicity and a power of the speech  
4 signal from the received bit stream, and  
5           said identification means performs  
6 identification operation using at least either one of  
7 the decoded pitch periodicity and the decoded power  
8 output from said decoding means.

15.           An apparatus according to claim 11, wherein  
2           said decoding means decodes information  
3 containing pitch periodicity and a power of the speech  
4 signal from the received bit stream, and  
5           said classification means performs  
6 classification operation using at least either one of  
7 the decoded pitch periodicity and the decoded power  
8 output from said decoding means.

16.           An apparatus according to claim 10, wherein  
2           said apparatus further comprises estimation  
3 means for estimating pitch periodicity and a power of  
4 the speech signal from the excitation signal and the  
5 decoded speech signal, and  
6           said identification means performs  
7 identification operation using at least either one of  
8 the estimated pitch periodicity and the estimated power  
9 output from said estimation means.

17.           An apparatus according to claim 11, wherein  
2               said apparatus further comprises estimation  
3 means for estimating pitch periodicity and a power of  
4 the speech signal from the excitation signal and the  
5 decoded speech signal, and  
6               said classification means performs  
7 classification operation using at least either one of  
8 the estimated pitch periodicity and the estimated power  
9 output from said estimation means.

18.           An apparatus according to claim 11, wherein  
2               said classification means classifies unvoiced speech by  
3 comparing a value obtained by the decoded filter  
4 coefficients from said decoding means with a  
5 predetermined threshold.

19.           A speech signal decoding/encoding method  
2 comprising the steps of:  
3               encoding a speech signal by expressing the  
4 speech signal by at least a sound source signal, a gain,  
5 and filter coefficients;  
6               decoding information containing a sound source  
7 signal, a gain, and filter coefficients from a received  
8 bit stream;  
9               identifying voiced speech and unvoiced speech  
10 of the speech signal using the decoded information;  
11               performing smoothing processing based on the

12 decoded information for at least either one of the  
13 decoded gain and the decoded filter coefficients in the  
14 unvoiced speech; and  
15 decoding the speech signal by driving a filter  
16 having the decoded filter coefficients by an excitation  
17 signal obtained by multiplying the decoded sound source  
18 signal by the decoded gain using a result of the  
19 smoothing processing.

20. A speech signal decoding/encoding apparatus  
2 comprising:

3 speech signal encoding means for encoding a  
4 speech signal by expressing the speech signal by at  
5 least a sound source signal, a gain, and filter  
6 coefficients;

7 a plurality of decoding means for decoding  
8 information containing a sound source signal, a gain,  
9 and filter coefficients from a received bit stream  
10 output from said speech signal encoding means;

11 identification means for identifying voiced  
12 speech and unvoiced speech of the speech signal using  
13 the decoded information;

14 smoothing means for performing smoothing  
15 processing based on the decoded information for at least  
16 either one of the decoded gain and the decoded filter  
17 coefficients in the unvoiced speech identified by said  
18 identification means; and

19                    filter means which has the decoded filter  
20 coefficients and is driven by an excitation signal  
21 obtained by multiplying the decoded sound source signal  
22 by the decoded gain, at least either one of the decoded  
23 filter coefficients and the decoded gain using an output  
24 result of said smoothing means.

## Abstract of the Disclosure

In a speech signal decoding method,  
information containing at least a sound source signal,  
gain, and filter coefficients is decoded from a received  
bit stream. Voiced speech and unvoiced speech of a  
5 speech signal are identified using the decoded  
information. Smoothing processing based on the decoded  
information is performed for at least either one of the  
decoded gain and decoded filter coefficients in the  
unvoiced speech. The speech signal is decoded by  
10 driving a filter having the decoded filter coefficients  
by an excitation signal obtained by multiplying the  
decoded sound source signal by the decoded gain using  
the result of the smoothing processing. A speech signal  
decoding apparatus is also disclosed.

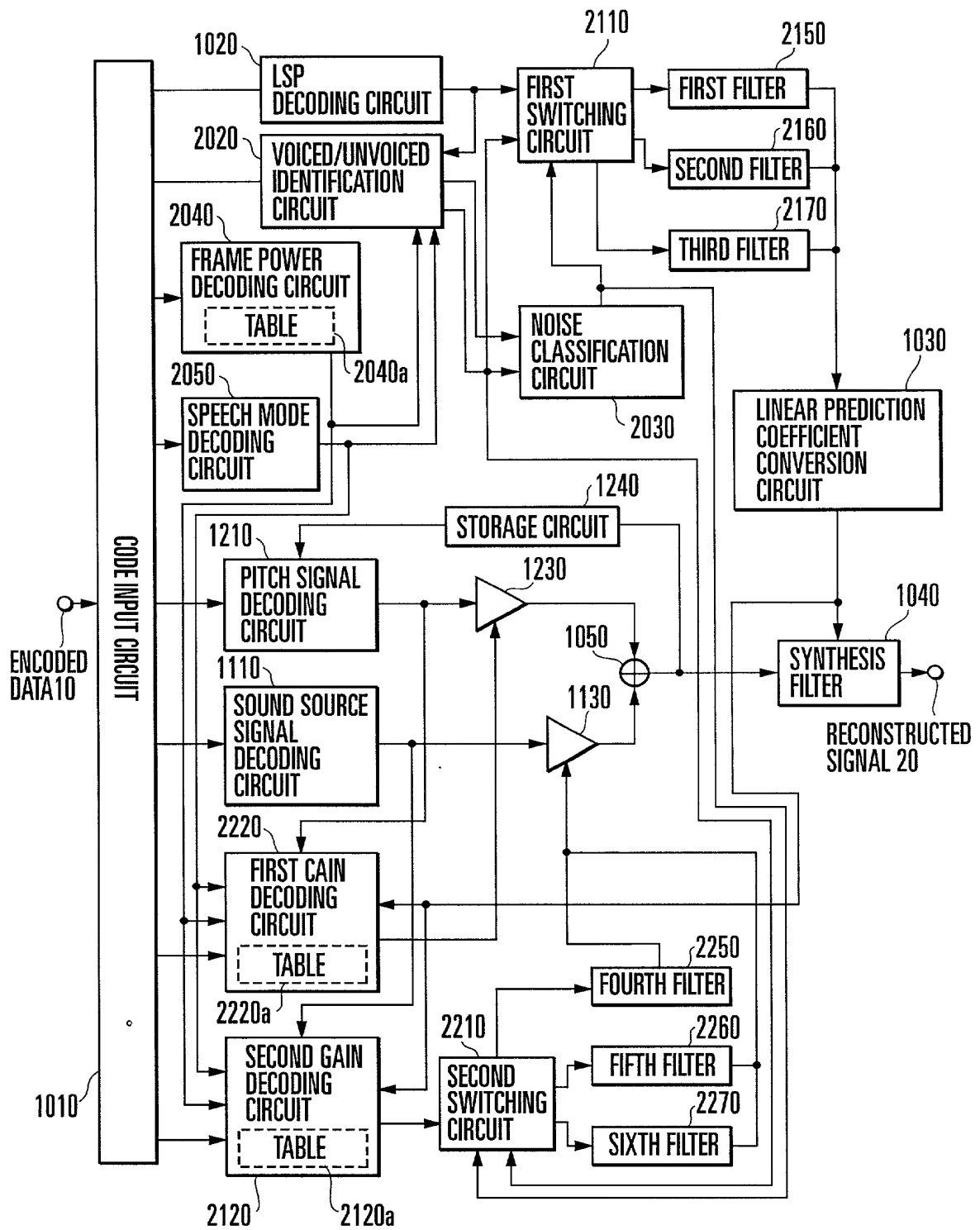


FIG. 1

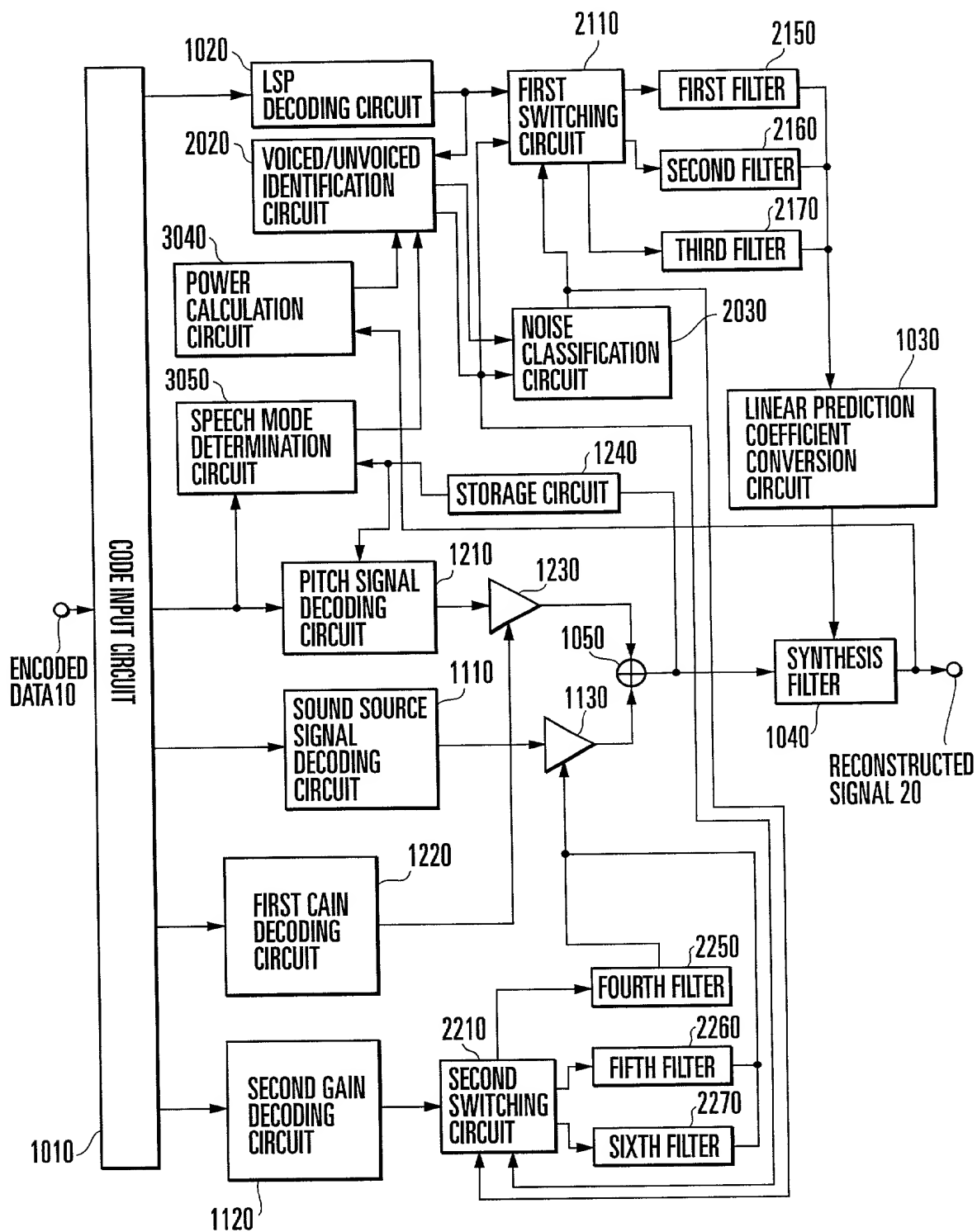


FIG. 2

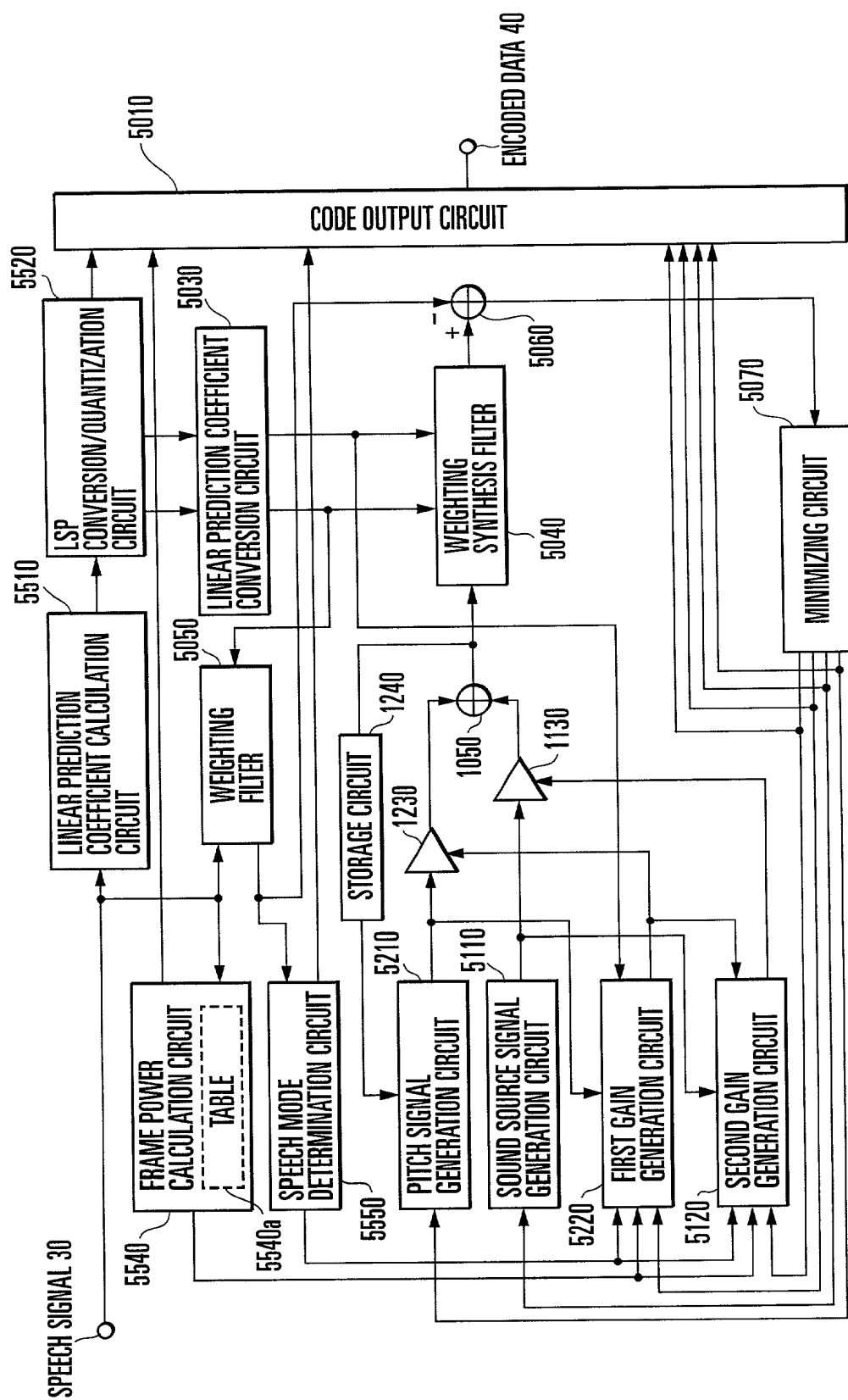
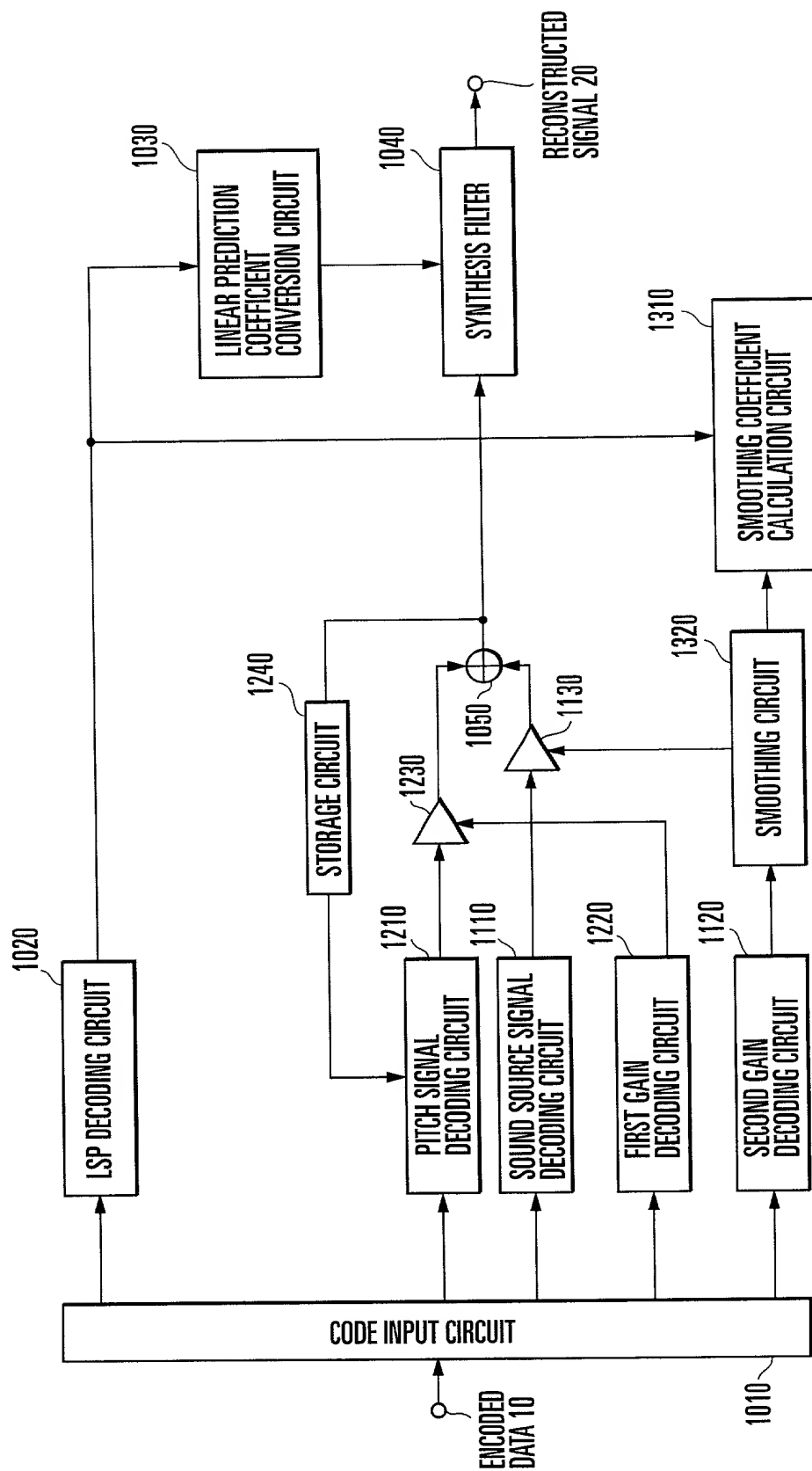


FIG. 3





**FIG. 4**  
**PRIOR ART**

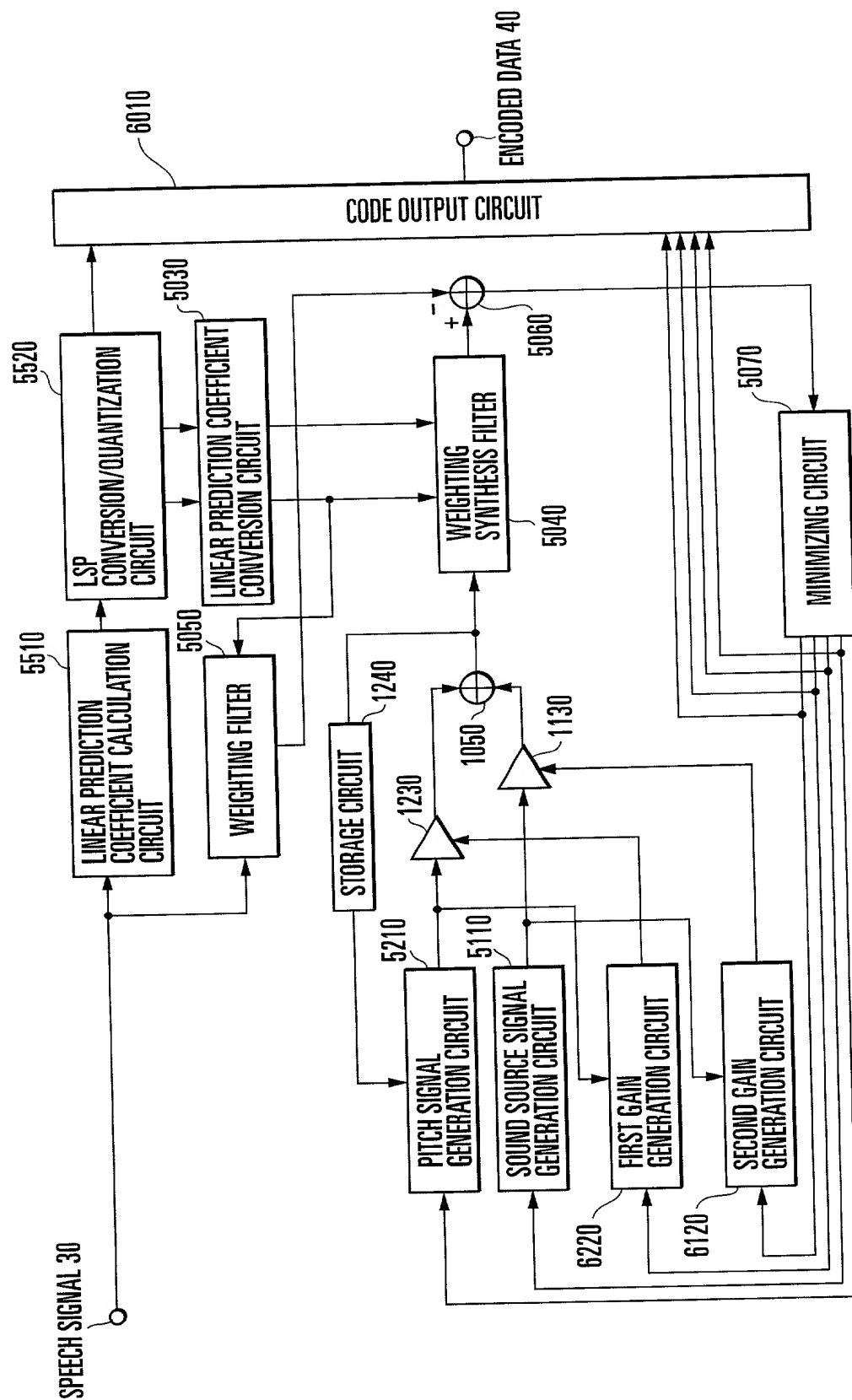


FIG. 5  
PRIOR ART

# DECLARATION AND POWER OF ATTORNEY

As a below named inventor, I hereby declare that:

My residence, post office address and citizenship are as stated below next to my name.

I believe I am the original, first and sole inventor (if only one name is listed below) or an original, first and joint inventor (if plural names are listed below) of the subject matter which is claimed and for which a patent is sought on the invention entitled:

**Speech Signal Decoding Method and Apparatus**

the specification of which is attached hereto unless the following box is checked:

☐ was filed on \_\_\_\_\_ as United States Application Number or PCT International Application Number \_\_\_\_\_ and was amended on \_\_\_\_\_ (if applicable).

I hereby state that I have reviewed and understand the contents of the above-identified specification, including the claims, as amended by any amendment referred to above.

I acknowledge the duty to disclose information which is known by me to be material to patentability as defined in Title 37, Code of Federal Regulations § 1.56.

I hereby claim foreign priority benefits under Title 35, United States Code, § 119(a)-(d) or § 365(b) of any foreign application(s) for patent or inventor's certificate, or § 365(a) of any PCT International application which designated at least one country other than the United States, listed below and have also identified below any foreign application for patent or inventor's certificate, or PCT International application having a filing date before that of the application on which priority is claimed:

## PRIOR FOREIGN APPLICATION(S)

NUMBER	COUNTRY	DAY/MONTH/YEAR FILED	PRIORITY CLAIMED
214292/1999	Japan	28/07/1999	Yes

I hereby claim the benefit under Title 35, United States Code § 119(e) of any United States provisional application(s) listed below.

APPLICATION NO.	FILING DATE

I hereby claim the benefit under Title 35, United States Code, § 120 of any United States application(s), or § 365(c) of any PCT International application designating the United States, listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in the prior United States or PCT International application in the manner provided by the first paragraph of Title 35, United States Code, § 112, I acknowledge the duty to disclose information which is known by me to be material to patentability as defined in Title 37, Code of Federal Regulations § 1.56 which became available between the filing date of the prior application and the national or PCT International filing date of this application:

APPLICATION SERIAL NO.	FILING DATE	STATUS: PATENTED, PENDING, ABANDONED

I hereby appoint as my attorneys, with full powers of substitution and revocation, to prosecute this application and transact all business in the Patent and Trademark Office connected therewith: Stephen A. Bent, Reg. No. 29,768; David A. Blumenthal, Reg. No. 26,257; William T. Ellis, Reg. No. 26,874; John J. Feldhaus, Reg. No. 28,822; Patricia D. Granados, Reg. No. 33,683; John P. Isacson, Reg. No. 33,715; Donald D. Jeffery, Reg. No. 19,980; Eugene M. Lee, Reg. No. 32,039; Richard Linn, Reg. No. 25,144; Peter G. Mack, Reg. No. 26,001; Brian J. McNamara, Reg. No. 32,789; Sybil Meloy, Reg. No. 22,749; George E. Quillin, Reg. No. 32,792; Colin G. Sandercock, Reg. No. 31,298; Bernhard D. Saxe, Reg. No. 28,665; Charles F. Schill, Reg. No. 27,590; Richard L. Schwaab, Reg. No. 25,479; Arthur Schwartz, Reg. No. 22,115; Harold C. Wegner, Reg. No. 25,258.

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I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

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Residence Address	Country of Citizenship	
Post Office Address		

Full Name of Fourth Inventor	Signature of Fourth Inventor	Date
Residence Address	Country of Citizenship	
Post Office Address		

Full Name of Fifth Inventor	Signature of Fifth Inventor	Date
Residence Address	Country of Citizenship	
Post Office Address		